

# The Solar Neighborhood VIII: Discovery of New High Proper Motion Nearby Stars Using the SuperCOSMOS Sky Survey

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## ABSTRACT

Five new objects with proper motions between  $1.0''/\text{yr}$  and  $2.6''/\text{yr}$  have been discovered via a new RECONS search for high proper motion stars utilizing the SuperCOSMOS Sky Survey. The first portion of the search, discussed here, is centered on the south celestial pole and covers declinations  $-90^\circ$  to  $-57.5^\circ$ .

Photographic photometry from SuperCOSMOS and *JHKs* near-infrared photometry from 2MASS for stars nearer than 10 pc are combined to provide a suite of new  $M_{Ks}$ -color relations useful for estimating distances to main sequence stars. These relations are then used to derive distances to the new proper motion objects as well as previously known stars with  $\mu \geq 1.0''/\text{yr}$  (many of which have no trigonometric parallaxes) recovered during this phase of the survey.

Four of the five new stars have red dwarf colors, while one is a nearby white dwarf. Two of the red dwarfs are likely to be within the RECONS 10 pc sample, and the white dwarf probably lies between 15 and 25 pc. Among the 23 known stars recovered during the search, there are three additional candidates for the RECONS sample that have no trigonometric parallaxes.

*Subject headings:* stars: distances — stars: luminosity function, mass function — stars: statistics — solar neighborhood — Galaxy: stellar content

## 1. Introduction

One of the primary goals of the Research Consortium on Nearby Stars (RECONS) is to discover stars that are currently missing from compendia of the Sun's nearest neighbors. As discussed in Henry et al. (1997), we estimate that as many as 30% of the nearby star systems lurk undiscovered within 10 parsecs, the horizon of the RECONS sample. The RECONS team is using both of the methods typically used to reveal nearby stars — high proper motion and photometric distance estimates — to discover new nearby systems. Here we report first results of a new initiative resulting in the discovery of five new high proper motion objects with  $\mu > 1.0''/\text{yr}$  in the region around the

south celestial pole, along with an analysis of the newly revised sample of all similarly defined high proper motion stars in the same region.

To date, Luyten and Giclas have provided the bulk of high proper motion star systems. The valuable *LHS Catalogue* (Luyten 1979a, hereafter LHS) is a compendium of stars that includes 3583 objects with annual proper motions greater than  $0.5''/\text{yr}$ . Included in this list are 525 stellar systems that have motions greater than  $1.0''/\text{yr}$ . Many of these systems were also reported by Giclas and collaborators (Giclas et al. 1971). Both the Luyten and Giclas surveys were monumental undertakings in an era before extensive computer power was available and electronic data mining

possible. Moreover, not all parts of the sky were covered uniformly in those surveys. Significantly lower completeness in the most southerly declinations is particularly noteworthy.

There is no doubt as to the scientific usefulness of the monumental Luyten and Giclas surveys; however there are two key shortcomings that have always dogged efforts to exploit those catalogues for quantifiably complete samples. First, the absolute astrometric accuracy of Luyten’s catalogue is poor by modern standards, making recovery of some of the catalogued objects very difficult (eg. Bakos et al. 2002). This is despite the availability of finder charts in the *LHS Atlas* (Luyten 1979b). Second, and more significantly, the completeness of surveys produced using a variety of techniques (including manual plate ‘blinking’) has been difficult to establish. Worries concerning the completeness of the LHS have been compounded over the past decade by a spate of new discoveries, for many of which there is no obvious reason as to why they were missed in the earlier surveys. Adding further fuel to the firey completeness debates is the fact that invariably newly discovered objects turn out to be rather interesting, because completeness is chiefly an issue at relatively faint magnitudes and high proper motions where new types of intrinsically faint, high velocity and potentially nearby stars tend to be found (eg. Hambly et al. 1997). Clearly, if there is a large and unquantifiable bias against certain classes of objects in the early surveys, then statistical corrections (eg. Dawson, 1986) can never hope to recover an accurate estimate of the true numbers of all types of star. Recently, however, the availability of homogeneous, multi-colour and multi-epoch Schmidt survey plate collections along with fast, high precision scanning machines capable of digitising them has enabled significant progress. An example is the SuperCOSMOS Sky Survey (hereafter SSS, Hambly et al. 2001a; that paper also briefly describes some of the other major digitisation programmes). These newly digitised sky surveys have enabled much progress in systematic trawls for high proper motion stars (eg. Ibata et al. 2000). Completeness questions can now be more accurately addressed (eg. Monet et al. 2000) and recovery of many of Luyten’s discoveries has become possible (eg. Bakos et al. 2002), in addition to discovery of new objects.

Thus, recent astrometric efforts to reveal high proper motion stars are meeting with continued success. Several studies investigating the southern sky have yielded new systems with  $\mu > 1.0''/\text{yr}$ . The large effort of Wroblewski and collaborators (Wroblewski & Costa 2001 and references therein) has resulted in discovery of two systems (WT 248 and WT 1827). The Calan-ESO survey of Ruiz and collaborators (Ruiz & Maza 1987 and Ruiz et al. 2001) has yielded three new systems (ER2, ER8, and CE 89). Work by Scholz and collaborators has used APM measurements of UK Schmidt Telescope survey plates (eg. Reyle et al. 2002; Lodieu et al. 2004; Scholz et al. 2000) and the SSS (eg. Scholz et al. 2002 and references therein) to reveal three systems (APMPM J1957–4216, APMPM J2330–4736, and SSSPM J2231–7514AB). The study of Oppenheimer et al. (2001) also used the SSS, and found new white dwarfs (eg. WD0205–053, WD0351–564, and WD2214–390). Furthermore, Pokorny et al. (2003) report a systematic high proper motion star survey employing SSS data; detailed follow-up of potentially interesting objects is underway by our group and others.

Astrometric searches of the northern sky also continue to yield high proper motion stars. In an innovative, systematic search of the sky north of declination  $-2.8^\circ$  and within  $25^\circ$  of the Galactic plane, Lepine et al. (2002) have found 18 new systems with  $\mu > 1.00''/\text{yr}$ , by far the most productive recent effort, while Teegarden et al. (2003) have reported a remarkable system with  $\mu = 5.06''/\text{yr}$  by searching the SkyMorph database of Near-Earth Asteroid tracking data (Pravdo et al. 1999).

In an effort to discover previously missed high proper motion objects in the southern sky, a new search by the RECONS team was initiated using SSS data. The new objects have been dubbed SCR sources, corresponding to the SuperCOSMOS RECONS search. In this paper we present the first results of this search, which includes five new objects with motions larger than  $1.0''/\text{yr}$  in only  $\sim 8\%$  of the entire sky. We have extracted *JHK*s photometry from 2MASS to provide an extended color baseline that permits accurate photometric distance estimates. In a follow-up paper (Henry et al. 2004) we will present further optical photoelectric photometry, spectroscopy and analysis of

accurate photometric parallaxes for the sample.

## 2. Trawling SuperCOSMOS Sky Survey data

The SSS (Hambly et al. 2001a) is ideally suited to systematic searches for high proper motion stars. The survey consists of multi-colour (*BRI*) Schmidt photographic observations with *R* at two distinct epochs, but in general all four passbands (plate magnitudes denoted by  $B_J$ ,  $ESO-R$ ,  $R_{59F}$ , and  $I_{VN}$ , and hereafter referred to as  $B_J$ ,  $R_1$ ,  $R_2$  and  $I$ ) were observed at different epochs separated by up to 50 years. Data for the entire southern hemisphere are currently publicly available (see Hambly et al. 2001a for details) and the survey programme is currently being extended into the northern hemisphere. As described above, there have been several searches for high proper motion stars using SSS data. Each has had a different emphasis, with different science goals.

The survey of Pokorny et al. (2003) is an automated search primarily using the two *R* band plates (UK and ESO Schmidt surveys) in each field of the SSS south of  $\delta = -20^\circ$ , aimed at cataloguing cool dwarfs to a lower proper motion limit of  $\mu = 0.18''/\text{yr}$ . The search methodology employs software-automated multiple-pass pairing between only two *R* plates, and necessarily has rather stringent limits on image quality (eg. profile class, proximity to bright stars and general morphology) to yield a clean catalogue of thousands of stars; the intention was that no manual sifting of this automatically generated catalogue would be required. The chief limitations of the search method are general incompleteness resulting from the stringent quality constraints, restriction of sky area covered due to necessary avoidance of crowded regions and incompleteness at high proper motions – c.f. Pokorny et al. (2003) Section 4 – due to spurious pairing at large image displacement.

The trawl employed by Oppenheimer et al. (2001) was similar to that of Pokorny et al. but was aimed at cool (but relatively blue) white dwarfs. Detections therefore relied on presence on the  $B_J$  plates as well as the two *R* plates, and hence less stringent quality cuts could be used to obtain a clean sample. This survey was also generalised to use *POSS-I* ‘E’ ( $\equiv R$ ) data in the equatorial

zone  $0^\circ > \text{Dec} > -20^\circ$  in lieu of *ESO-R* material, but employed a proper motion threshold of  $\mu = 0.33''/\text{yr}$ . In this case, some visual checking of the available source image data was employed after selection of stars via colour and reduced proper motion. However, the Oppenheimer et al. (2001) survey also suffered from the same incompleteness problems at high proper motions, and inability to probe more crowded, lower latitude regions of sky.

### 2.1. New search methodology

For the purposes of supplying candidates for RECONS, a new search strategy is being employed that attempts to circumvent the completeness problems of previous SSS efforts by a combination of full use of all astrometric information between the four plates available in every field, and relaxed quality/morphology criteria along with a final step of manual sifting to produce clean target lists. In some ways this is an unsatisfactory return to the Luyten-style approach by including a subjective human element to the process, but it seems that at least for surveys employing parameterised image detection lists this is the only way of ensuring high levels of completeness. Ultimately, it is likely that a whole-sky application of a pixel-based process like the SUPERBLINK algorithm of Lepine et al. (2002) is the only way of attaining the highest possible completeness from digitised Schmidt plate scans; even then the problems of saturation and scattered light near bright stellar cores remain (hence, areal completeness and completeness for close binaries will never be close to 100%).

Briefly, the new SCR search starts with each individual set of parameterised detections (the so-called Image Analysis Mode data – see Hambly et al. 2001b) from all plates in the same field positionally error-mapped to a common co-ordinate system using a rigorous application of the Evans & Irwin (1995) error mapping algorithm. The default SSS pairing (Hambly et al. 2001c) is then used to exclude all images that appear on all four plates having astrometric solutions indicating proper motion less than the limit (here,  $0.4''/\text{yr}$ ) along with goodness-of-fit parameter  $\chi^2 < 1.0$ . Then, all images that are either unpaired or have inconsistent astrometric solutions (resulting from erroneous matching in the simple default SSS scheme) are processed one by one in all

possible combinations amongst the available measurements out to a maximum displacement dictated by the upper proper motion limit chosen for the survey (here,  $10''/\text{yr}$ ) and the maximum epoch difference between the set of plates. This ‘brute force’ approach is made possible by modern computers and storage which are capable of processing large amounts of data at high IO bandwidth. The other innovation in our latest SSS trawl for RECONS is that single cuts in a range of quality/morphology parameters are not made; rather a set of warning conditions is defined at levels set by maximising completeness with respect to the LHS (at the same time endeavouring to minimise contamination by spurious detections to make the final manual sifting problem tractable). A violation threshold is set such that only when three quality conditions are violated for a four plate detection (two for a three plate detection) will a candidate be thrown away as certainly dubious.

The SCR search is being carried out starting at the south celestial pole and is moving north. This paper describes the first phase of the search, which includes the region from  $\delta = -90^\circ$  to  $-57.5^\circ$ . Figure 1 shows the fields currently surveyed. Number labels in Figure 1 are ESO/SRC standard Schmidt survey field designations; black areas represent fields included while white areas indicate fields currently excluded due to crowding problems (areas of low Galactic latitude or areas within the Magellanic Clouds). In total,  $\sim 8\%$  of the sky has been searched in this first effort.

The initial sift of the SSS dataset for RECONS included sources with proper motions determined to fall between  $0.4''/\text{yr}$  and  $10.0''/\text{yr}$ , and magnitude  $R < 16.5$ . The primary goal is to discover objects moving faster than  $\mu = 0.5''/\text{yr}$ , but the lower boundary on  $\mu$  was chosen to be  $0.4''/\text{yr}$  so that LHS objects with motions near  $0.5''/\text{yr}$  could be recovered if computed proper motion was slightly less than the cutoff due to measurement errors in either SSS data or the LHS.

## 2.2. Statistics of Results

The total number of candidate objects detected with  $\mu_{SCR} = 0.4\text{--}10.0''/\text{yr}$  in this initial search was 897. Spurious high proper motion detections can arise due to plate defects, blended sources and halo ‘sources’ around bright stars (for example, we note that the list of Pokorny et al. 2003 contains

8 apparently spurious sources having  $\mu > 4''/\text{yr}$  – one at more than  $10''/\text{yr}$ ). A multi-step sifting process was used to vet the SCR search candidates for true and false detections, including checks of magnitudes, colors, and image ellipticities. The  $R_1$  and  $R_2$  magnitudes were checked for consistency, and the colors were examined to determine whether they matched that of a real object, i.e. both  $B - R_2$  and  $B - I$  positive, or both negative. If the candidate passed both checks, it was passed on to the visual inspection stage.

In cases where a candidate failed the first two tests, the ellipticity quality flag was also checked. Experience revealed that if two or more image ellipticities were larger than 0.2, the object was spurious. Detections that failed all three tests were classified as false without visual inspection. As a final check, all of the 99 candidates found between  $\delta = -90$  and  $-80$  were inspected visually (regardless of the checks), and all fell into the appropriate true or false detection bins.

For the true detections, coordinates were cross-correlated with the SIMBAD database and the NLTT catalog. If the coordinates agreed to within a few arcminutes and the magnitudes and proper motions were consistent, the detection was labeled as previously known. For detections without known proper motion counterparts, visual inspection definitively confirmed or refuted a real proper motion object. In a few cases, the coordinates agreed well, but the magnitudes did not. Several of these near matches turned out to be new common proper motion companions to a previously known proper motion object.

In summary, these checks revealed 443 false detections (49% of the candidates); additionally, 72 of the 897 candidates were duplicate detections resulting from the generous ESO/SRC plate overlap regions. Of the resulting 382 real, distinct objects, 262 were recoveries of previously cataloged objects, including many LHS/LTT objects and stars from the other surveys mentioned in Section 1. Finally, 120 (13% of the initial candidate list) were found to be new discoveries, including a handful of new common proper motion companions to already known primaries.

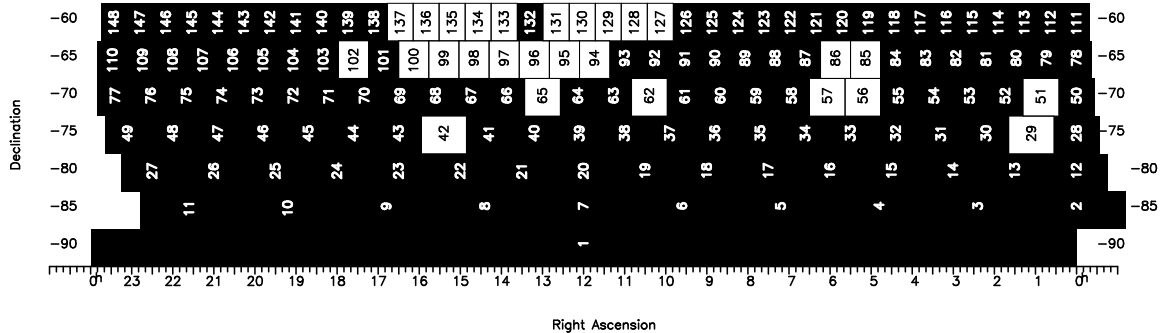


Fig. 1.— ESO/SRC standard fields covered in the SCR survey so far. Black cells indicate included fields; white cells indicate that the field was too crowded to be reliably analysed using the current data and algorithm (such fields have an unfavourable spread of epochs amongst the four SSS plates or are heavily crowded, being at low Galactic latitudes or near the cores of the Magellanic Clouds). Each field covers  $\sim 25$  square degrees of distinct sky (ie. not including any overlap regions) and we have covered 121 out of 148 possible ESO/SRC fields. Hence, the sky area covered so far is  $\sim 3000$  square degrees, or  $\sim 8\%$  of the whole celestial sphere.

### 3. Data from SuperCOSMOS — Astrometry and Plate Photometry

Of the 120 new objects discovered and the 262 known objects recovered in this phase of the SCR effort, we concentrate here on the subsample of 28 stars with  $\mu_{SCR} \geq 1.0''/\text{yr}$ , which are listed in Table 1. Names for the five new SCR stars are given in the first column (finder charts are given in Figure 2), whereas the known names are given for the remaining 23 stars. Also listed are the SSS photographic astrometry and photometry for all 28 objects. Coordinates are precessed and proper motion corrected to equinox and epoch J2000.0, and are accurate to  $\pm 0.3$  arcsec. Proper motions (and their errors) and the position angles for each target are given.

We quote photometry in Table 1 from the UK Schmidt R original survey plates ( $R_2$ ) because these data are, in general, of higher signal-to-noise and more uniformly calibrated than that from the ESO-R copy plates ( $R_1$ ). In addition, red objects sometimes do not have reliable detections at  $B_J$ , while blue objects are often faint on  $I$  plates. Note that the absolute calibration of the individual passbands is subject to systematic errors that increase as the brightness of the source increases (Hambly et al. 2001b). However, because corrections to colours are applied to the data with respect to the  $B_J$  plates, these systematic errors are not present in colour indices (eg.  $B_J - R_2$ ,

$R_2 - I$ ). Consequently, the relative accuracy of SSS colour indices is much better than the absolute accuracy of individual passband photometry. As expected, the five new stars are fainter ( $R_2 = 14.12$  to  $16.33$ ) than nearly all of the known stars ( $R_2 = 7.49$  to  $14.99$ ) except the double white dwarf system ( $R_2 = 15.82$  and  $16.21$ ) found by Scholz et al. (2002) using SuperCOSMOS data.

#### 3.1. Completeness and other checks

We make no claim as to the absolute completeness of our new SCR search at this preliminary stage. However, we note that in the area surveyed, there are 169 LHS stars; we recover 127 of these. At first sight, this success rate of 75% seems rather poor, but this test requires closer examination. The LHS catalog is biased (particularly so in the southern hemisphere) towards brighter magnitudes, and the SCR search employs deep, sky-limited Schmidt survey plates upon which stars with  $m < 10$  have heavily saturated and large, extended images. Moreover, the surveyed region in Figure 1 is at generally low Galactic latitude. LHS objects missed by our procedure are lost because of blending problems on the source plates and the consequent failure of the standard SuperCOSMOS image analysis software (Hambly et al. 2001b) in unscrambling and/or accurately parameterising deblended components. This is illustrated in Figure 2, where the  $B_J$  images of SCR1845–6357 and SCR1848–6855 are blended to such an extent as

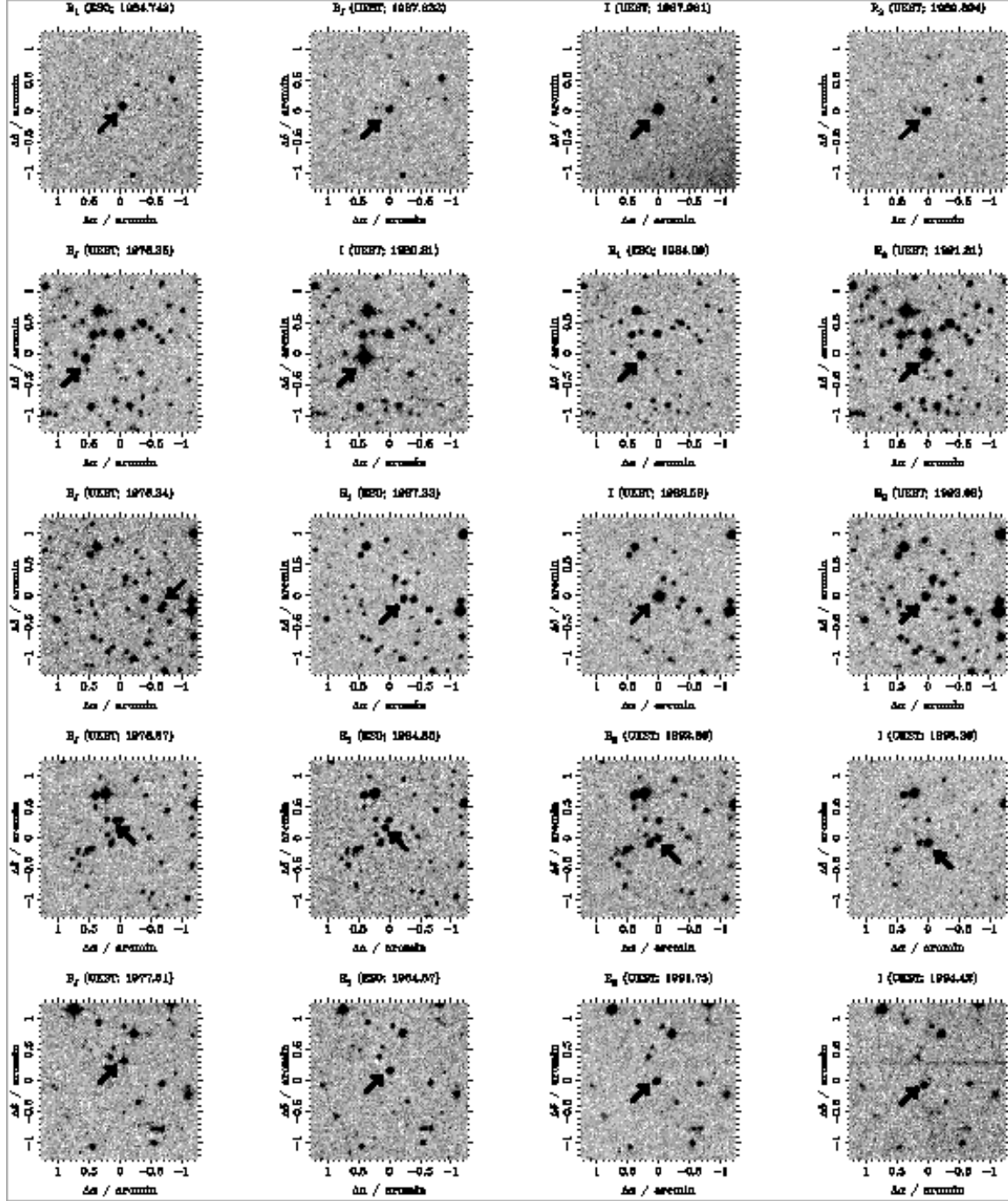


Fig. 2.— ‘Postage stamp’ finders for the five newly discovered high proper motion stars. Rows are (i) SCR0342–6407; (ii) SCR1138–7721; (iii) SCR1845–6357; (iv) SCR1848–6855; and (v) SCR2012–5956. In each case, the four images are the  $B_J$ ,  $R_1$ ,  $R_2$  and  $I$  images in chronological order. Black arrows indicate the star in question in each case.

to render their  $B_J$  parameters unusable (eg. Table 1). Blending is particularly problematic for brighter images, and as already stated the deep sky-limited Schmidt survey plates are not well suited to studies of stars brighter than  $m \sim 10$ . If we limit the LHS completeness comparison to magnitudes  $R > 10.0$ , we recover 112 out of 130 stars — a somewhat improved 86% success rate. If we further limit the comparison to stars with  $\mu > 1.0''/\text{yr}$ , we recover 18 out of 18 LHS stars — 100% success. Hence our search is most successful in the region of parameter space where the LHS is least complete: at fainter magnitudes and high proper motions. Note that images of moving stars are more susceptible to crowding than non-moving stars. If a high proper motion star is irretrievably blended on one R plate or on two or more of any of the four SSS plates, the SCR trawl will not detect it. Images of slow moving stars are, of course, likely to be isolated on all plates if they are isolated on one; this is not the case for fast moving stars, especially when they are traversing a crowded field. If we compare SCR success versus LHS for  $\mu > 1.0''/\text{yr}$  *without* a magnitude cut of  $R > 10.0$ , we recover 20 out of 29 stars — this low success rate of 69% illustrates the difficulty of finding bright, high proper motion stars using deep, sky-limited Schmidt plates. These 20 stars are listed in Table 1 with their LHS numbers.

The sample of 127 recovered LHS objects provides a control against which the SCR astrometric measurements were compared. In Figures 3 and 4 we show a comparison of our astrometric results with those of the LHS as originally published and using revised data (Bakos et al. 2002). In both cases, positions have been precessed and proper motion corrected to a common equinox and epoch (J2000.0 for both). Interestingly, although the Bakos et al. positions are far superior to the original LHS values, their proper motion determinations are clearly inferior, even allowing for the objects labelled ‘B’ or ‘b’ in their list (open circles in Figure 4). The SCR and LHS proper motions are in much better agreement, indicating the quality of Luyten’s original measurements. While the Bakos et al. positions are a vast improvement and enable easy recovery of LHS stars (eg. as has been done here), their proper motion estimates should not be used in place of the original LHS measurements.

#### 4. Data from 2MASS — Infrared Photometry

The infrared  $J$ ,  $H$ , and  $Ks$  photometry has been extracted from 2MASS by OASIS. Because these objects are high proper motion stars, all of them were manually identified by comparison with finding charts instead of retrieving data by setting a search radius around a given RA and Dec. The photometry is given in Table 2 for both the new SCR stars and the known stars. The errors (and here we adopt the  $x_{m\text{sigcom}}$  errors where  $x$  is  $j$ ,  $h$ , or  $k$ ) that give a measure of the total photometric uncertainty, including global and systematic terms) are 0.02 to 0.03 mag in most cases, and are less than 0.05 mag in all cases except SCR2012–5956 (0.11 at  $H$  and no given error at  $Ks$  because it is at the limit of  $Ks$  band detectability), J2231–7515 (0.06 at  $H$  and 0.12 at  $Ks$ ), and J2231–7514 (0.06 at  $H$  and 0.08 at  $Ks$ ). The 2MASS frames have also been used to confirm the proper motion for all five newly discovered stars.

The infrared photometry is useful because it permits a color extension from the optical  $B_J$  band to  $Ks$ , thereby spanning more than a factor of four in effective wavelength. Diagnostics bridging the photographic and infrared bands are particularly good for the detection of blue and very red objects.  $(R_2 - Ks)$  is given in Table 2 as a color indicator because for the faintest red objects  $B_J$  is not available. Given that SCR2012–5956 is a fast-moving, faint object, yet appears rather blue, with  $(R_2 - H) = 0.40$  (the value for  $R_2 - Ks = 0.22$  is suspect because of the 2MASS faint  $Ks$  limit), it is almost certainly a white dwarf. Computation of its reduced proper motion  $H_R = m_R + 5 \log \mu + 5$  and  $(B_J - R_2)$  places it firmly in the region of spectroscopically confirmed white dwarfs in Figure 1 of Oppenheimer et al. (2001). It is also evident that SCR1845–6357 is a very red object ( $R_2 - Ks = 7.82$ ), and therefore likely to be quite close, given its bright apparent magnitudes.

#### 5. New Relations for Estimating Photometric Distances

In order to develop reliable color- $M_{Ks}$  relations, both SuperCOSMOS and 2MASS were searched for stars in the RECONS 10 pc sample. These stars are used because they generally have high quality trigonometric parallax values and have

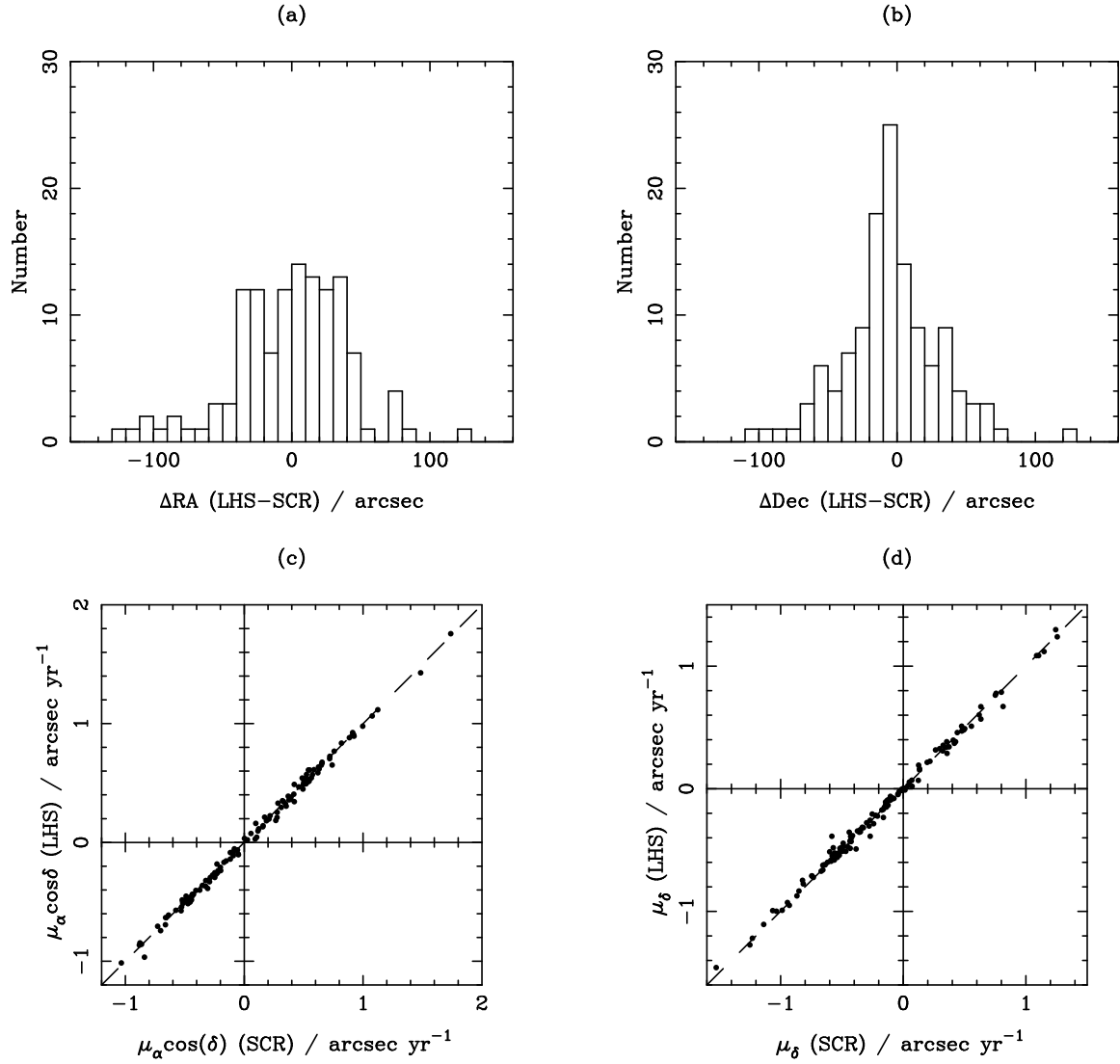


Fig. 3.— Comparison of LHS astrometry with new data from the SCR search: (a) Right Ascension; (b) Declination; (c) proper motion in RA; and (d) proper motion in Dec. Dashed lines in (c) and (d) are  $y = x$  lines indicating perfect agreement.



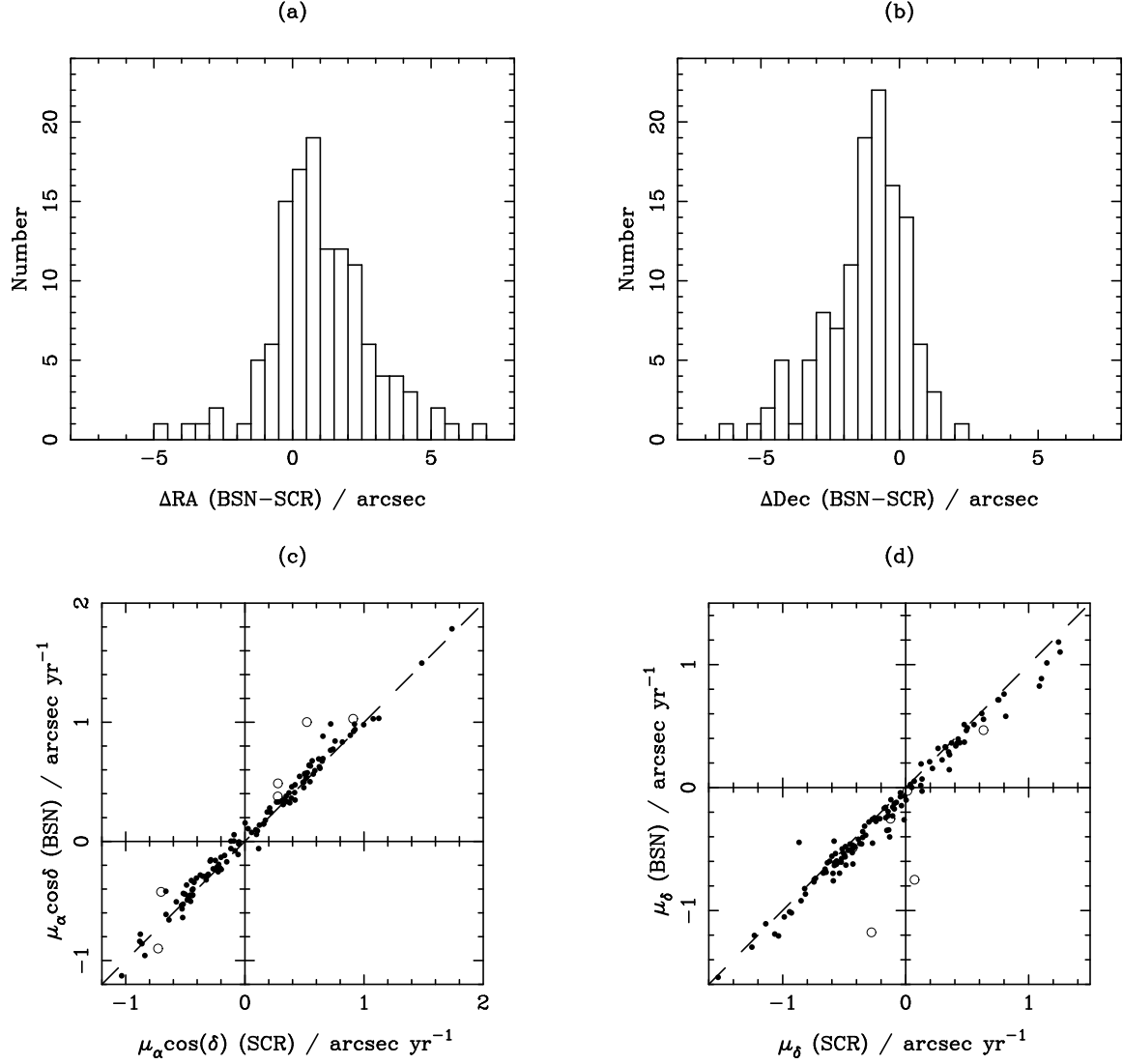


Fig. 4.— Comparison of revised astrometry (Bakos et al. 2002) with new data from the SCR search for LHS stars: (a) Right Ascension; (b) Declination; (c) proper motion in RA; and (d) proper motion in Dec. Open circles in (c) and (d) indicate sources for which Bakos et al. report unreliable proper motion measurement “for some reason”.

been vetted better than any other sample of stars for close companions that would corrupt flux and color measurements.

Photographic  $B_J$ ,  $R_2$  and  $I$  magnitudes were extracted for all stars south of the current declination cutoff of SuperCOSMOS ( $+3.0^\circ$ ). Single stars with reliable (unblended, unsaturated) photographic magnitudes were then examined in 2MASS, from which  $JHKs$  photometry was obtained. The final cut provided 54 main sequence, single, stars with reliable magnitudes in all six bandpasses. These were supplemented with one additional object, GJ 1001 B = LHS 102 B, an L dwarf found in all bands but  $B_J$  (the complete sample and magnitudes can be obtained from the authors upon request).

In total, there are 15 possible color- $M_{Ks}$  relations that can be derived from the six bandpasses. Of these,  $(B_J - R_2)$ ,  $(J - H)$ ,  $(J - K)$ , and  $(H - K)$  are not useful because in each case the range in color is quite restricted and does not predict reliable  $M_{Ks}$  values. The remaining 11 relations are used as an ensemble to generate up to 11 different distance estimates for each star, provided that the star's color falls within the valid range. Each relation is locked to  $M_{Ks}$  because practically all undiscovered nearby stars (and many brown dwarfs) of interest will have a reliable  $Ks$  in 2MASS. Four exemplary relations are illustrated in Figure 5. The  $(B_J - I)$  and  $(B_J - Ks)$  relations represent the largest range in color for photographic only and photographic/infrared colors. The  $(B_J - Ks)$  relation, in particular, shows the great strength in combining optical and infrared data, spanning more than six full magnitudes in color. The less reliable  $(R_2 - I)$  and  $(I - J)$  relations are also illustrated. In these cases, the colors span only  $\sim 3.5$  magnitudes, and the scatter in the photographic magnitudes compromises the relations. Nonetheless, they still add weight to the final ensemble distance estimates. Details for each fit, including the number of objects used to create the fit, its applicable range, the coefficients, and the RMS in magnitudes, are given in Table 3.

To provide a measure of the ensemble technique's reliability, the RECONS stars of known distance have been run back through the relations. Each star has up to 11 different distance estimates that are combined to produce a mean distance estimate and error, represented by the standard de-

viation of the individual estimates. The average offset between the estimated and true distances is 26%, which is remarkable given the imprecise nature of the photographic magnitudes, and of course, the intrinsic cosmic scatter in the stars due to metallicity and age effects. These relations can be used within the stated ranges for single, main sequence stars with reliable magnitudes found in SuperCOSMOS and 2MASS. The distances derived using these relations will, of course, not be reliable for subdwarfs. Even for main sequence stars, in a few cases the effects of age and metallicity will be severe enough that the predicted and true distances will differ by more than 50%, as is the case for seven of the 55 stars used in the relations. In comparison, 14 of the 55 stars have estimated distances within 10% of their true distances.

## 6. Discussion

Table 4 gives distance estimates and errors for the new SCR discoveries and the previously known stars that were recovered during the SCR search. Two of the four red SCR stars are likely to be within the 10 pc horizon of RECONS. SCR1845-6357 is likely to be one of the nearest few dozen stars. Based on preliminary CCD  $VRI$  photometry and photometric distance relations for white dwarfs, we estimate a distance of  $\sim 15$ – $25$  pc for SCR2012-5956.

Only 11 of the 23 previously known objects have trigonometric parallax measurements, as given in the Yale Parallax Catalogue (van Altena et al. (1995) and from the Hipparcos mission (ESA 1997). In general those that have trigonometric distances match the distance estimates well, although LHS 128 and LHS 531 may be unresolved multiples because they are significantly further than predicted. All of the SCR discoveries and previously known stars without trigonometric measurements that are predicted to be within 25 pc have been included in our Cerro Tololo Interamerican Observatory Parallax Investigation (CTIOPi), as indicated in the notes column. Several of these stars will likely fall within the 10 pc horizon of the RECONS sample.

It is useful to assess briefly the complete, whole-sky sample of high proper motion stars as it is currently known. At Georgia State one of the authors

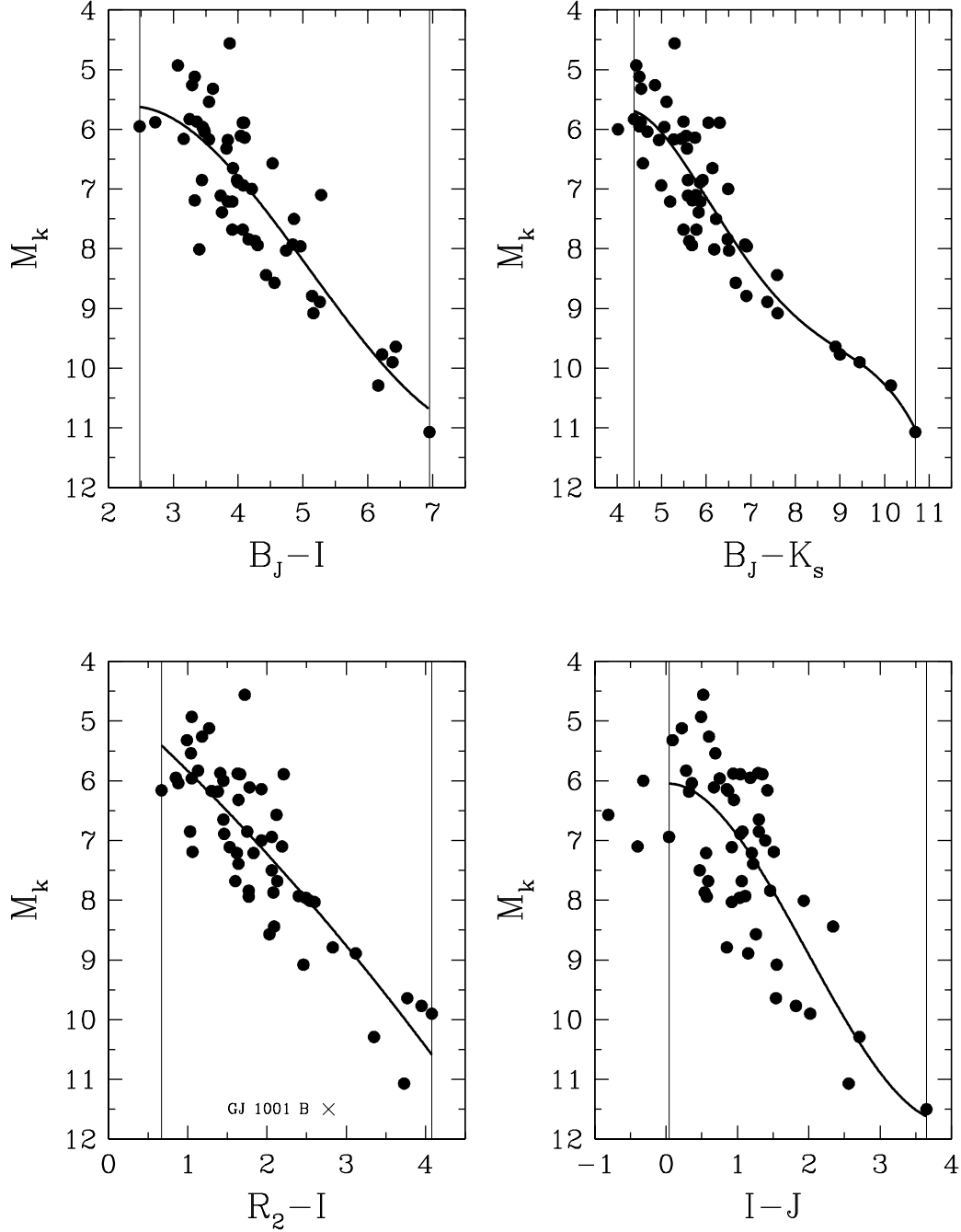


Fig. 5.— Four representative *color* –  $M_{Ks}$  relations used to estimate distances to main sequence stars. The points are for stars within 10 pc. Details about the fits are given in Table 3. In the  $(R_2 - I)$  plot, the X represents the L dwarf GJ 1001B = LHS 102B, which was not used in the fit because the relation doubles back at such faint  $M_Ks$ .

of this work (Jao) has compiled a comprehensive list of objects with  $\mu > 1.0''/\text{yr}$ . Although this list is the subject of a future paper, we note here that the distribution of systems is, as expected, tipped to the north. As of January 1, 2003, the counts of published systems in sky quartets of equal area are 143 from  $\delta = +90$  to  $+30$ , 153 from  $\delta = +30$  to  $+00$ , 127 from  $\delta = -00$  to  $-30$ , and 126 from  $\delta = -30$  to  $-90$ , yielding a total of 549 systems. The 8% overabundance in the north is an indicator that more fast moving systems are likely to be found at southern declinations. The five new objects reported here are another step toward rectifying this incompleteness in the southern sky.

## 7. Conclusions

The five new stars reported here provide important new nearby star candidates, with proper motions ranking them in the top few hundred stellar systems. The two fastest movers, SCR1845–6357 and SCR1138–7721, rank respectively as the 34th and 54th fastest proper motion systems known. These are merely the harbingers of a set of new high proper motion objects that remain to be discovered in the southern sky using SuperCOSMOS Sky Survey data. In a follow-up paper (Henry et al. 2004) we present accurate optical photoelectric photometry and spectroscopy of high proper motion objects in this portion of the SCR survey, thereby revealing their true nature and allowing us to refine the distance estimates. In addition to the five stars highlighted here, there are 116 additional new discoveries with  $\mu = 0.4\text{--}1.0''/\text{yr}$  that will also be the subjects of future efforts.

Such nearby stars are, of course, useful for bolstering the population statistics of the Galaxy, and move us closer to an accurate census of the Sun's neighbors. The momentum for discovering new nearby stars comes from many directions, including the identification of systems for stellar mass determinations, planet searches, the detection of signatures of life, and SETI, simply because proximity is a key element in any search in which resolution is required or the intrinsic signals may be weak. The SCR search reported here is merely in its initial phase and will undoubtedly reveal many new nearby stars as we continue to push northward. This astrometric search is complementary to photometric and spectroscopic searches for

nearby stars, such as Reid & Cruz (2002) and Henry et al. (2002). All of these searches continue to yield new nearby stars, bringing about a sort of nearby star renaissance, as large scale surveys and significant computer power are turned to the discovery of solar neighbors.

## 8. Acknowledgements

Funding for the SuperCOSMOS Sky Survey is provided by the UK Particle Physics and Astronomy Research Council. NCH would like to thank colleagues in the Wide Field Astronomy Unit at Edinburgh for their work in making the SSS possible; particular thanks go to Mike Read, Sue Tritton and Harvey MacGillivray. Acknowledgements concerning the source photographic material of the SSS can be found in the survey papers cited herein.

The RECONS team at Georgia State University wishes to thank NASA's Space Interferometry Mission for its continued support of our study of nearby stars.

This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

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TABLE 1  
 SUPERCOSMOS–RECONS SEARCH DATA FOR OBJECTS WITH  $\mu > 1.0''/\text{yr}$  AND  $R < 16.5$  FOUND  
 BETWEEN  $\delta = -57.5^\circ$  AND  $-90^\circ$ .

Object	RA <sup>a</sup> (J2000.0)	Dec <sup>a</sup>	$\mu^b$	$\sigma_\mu^b$	PA <sup>b</sup>	$R_2^c$	$(B_J - R_2)^c$	$(R_2 - I)^c$	Notes
New discoveries:									
SCR0342–6407	03 42 57.44	−64 07 56.4	1.071	0.023	141.42	15.13	2.04	2.79	short time span for $\mu$
SCR1138–7721	11 38 16.82	−77 21 48.8	2.141	0.007	286.77	14.12	2.33	2.66	found twice
SCR1845–6357 <sup>d</sup>	18 45 05.09	−63 57 47.7	2.558	0.012	74.80	16.33	...	3.80	blended in $B_J$
SCR1848–6855	18 48 21.14	−68 55 34.5	1.287	0.013	194.38	16.07	...	2.11	blended in $B_J$
SCR2012–5956	20 12 31.79	−59 56 51.6	1.440	0.011	165.62	15.63	1.03	0.50	blue object
Previously known objects:									
LHS 124	00 49 29.05	−61 02 32.8	1.126	0.019	93.86	10.78	2.33	1.59	
LHS 128	00 57 19.78	−62 14 43.7	1.061	0.023	81.32	8.40	2.16	0.94	
LHS 145	01 43 00.99	−67 18 30.5	1.083	0.013	197.36	13.18	0.58	0.27	
LHS 150	02 07 23.25	−66 34 11.5	1.773	0.022	78.48	9.79	2.40	1.33	
LHS 160	02 52 22.18	−63 40 47.6	1.174	0.017	58.16	9.80	2.36	1.58	
LHS 195	04 38 22.35	−65 24 57.6	1.437	0.013	30.11	8.70	1.17	0.75	
LHS 199	04 55 57.72	−61 09 46.6	1.102	0.011	124.08	10.92	2.31	1.67	
LHS 204	05 13 05.30	−59 38 43.9	1.079	0.010	58.97	7.49	1.18	0.44	poor photometry <sup>e</sup>
LHS 205	05 16 59.72	−78 17 20.6	1.139	0.012	177.15	10.74	2.09	1.67	
LHS 34	07 53 08.15	−67 47 31.6	2.128	0.009	135.75	13.55	1.02	0.45	
LHS 263	09 17 05.36	−77 49 23.7	1.045	0.009	141.21	12.15	2.02	2.27	
LHS 268	09 24 20.94	−80 31 21.1	1.284	0.011	11.94	9.37	1.19	0.25	
LHS 271	09 42 46.45	−68 53 06.0	1.150	0.008	357.17	11.24	2.52	2.22	
LHS 328	12 28 40.09	−71 27 51.4	1.183	0.010	338.89	12.88	1.93	1.83	
LHS 329	12 28 43.10	−71 27 56.4	1.172	0.007	338.10	14.99	2.00	2.31	
LHS 475	19 20 54.36	−82 33 16.3	1.278	0.012	164.26	11.83	1.91	1.69	
LHS 493	20 28 03.78	−76 40 15.9	1.444	0.011	149.11	12.93	1.97	2.20	
LHS 499	20 51 41.64	−79 18 40.1	1.221	0.013	143.89	10.81	2.25	1.38	
PJH 4051	21 15 15.20	−75 41 52.4	1.079	0.009	143.58	13.37	2.10	2.24	Pokorny et al. (2003)
J2231–7515	22 30 33.46	−75 15 24.3	1.865	0.007	167.59	16.21	1.78	0.64	Scholz et al. (2002)
J2231–7514	22 30 39.95	−75 13 55.3	1.873	0.008	167.57	15.82	1.45	0.60	Scholz et al. (2002)
LHS 531	22 55 45.46	−75 27 31.4	1.484	0.011	224.20	9.39	2.17	1.93	
LHS 532	22 56 24.69	−60 03 49.4	1.076	0.011	208.73	13.19	2.21	2.53	

<sup>a</sup>Coordinates are precessed and proper motion corrected to equinox and epoch J2000.0, and are accurate to  $\pm 0.3$  arcsec (eg. Hambly et al. 2001c).

<sup>b</sup>Units of proper motion are arcsec/yr; position angle (PA) is measured in degrees east of north.

<sup>c</sup>As described in the text, individual passbands magnitudes are only accurate to  $\sim 0.3^m$ , while color indices are accurate to  $\sim 0.1^m$ . Passbands are photographic:  $B_J$ ,  $R_{59F}$ ,  $I_{VN}$ .

<sup>d</sup>This object was also discovered in the final survey of Pokorny et al. (2004).

<sup>e</sup>This object is very bright, and has a heavily saturated  $R_2$  image – here, we have quoted  $R_1$  (ESO–R) photometry, but note that all the photographic photometry for this object is potentially subject to large systematic errors.

TABLE 2  
INFRARED PHOTOMETRY FOR OBJECTS WITH  $\mu > 1.0''/\text{YR}$  AND  $R < 16.5$  FOUND BETWEEN  $\delta = -57.5^\circ$   
AND  $-90^\circ$ .

Object	$J$	$H$	$Ks$	$(R_2 - Ks)$	Notes
New discoveries:					
SCR0342-6407	11.32	10.89	10.58	4.55	
SCR1138-7721	9.40	8.89	8.52	5.60	
SCR1845-6357	9.54	8.97	8.51	7.82	very red
SCR1848-6855	11.89	11.40	11.10	4.97	
SCR2012-5956	14.93	15.23	15.41	0.22	white dwarf, $Ks$ suspect
Previously known objects:					
LHS 124	8.63	8.09	7.84	2.94	
LHS 128	7.08	6.49	6.28	2.12	
LHS 145	12.87	12.66	12.58	0.60	white dwarf
LHS 150	8.13	7.61	7.36	2.42	
LHS 160	7.67	7.12	6.83	2.97	
LHS 195	8.51	8.19	8.09	0.61	
LHS 199	9.04	8.51	8.31	2.61	
LHS 204	8.32	8.05	8.00	-0.51	poor photographic photometry
LHS 205	8.07	7.44	7.20	3.55	
LHS 34	12.73	12.48	12.36	1.19	white dwarf
LHS 263	8.33	7.77	7.45	4.71	
LHS 268	8.89	8.53	8.46	0.91	
LHS 271	7.95	7.39	7.04	4.20	
LHS 328	9.81	9.30	9.05	3.83	
LHS 329	10.98	10.50	10.18	4.81	
LHS 475	8.56	8.00	7.69	4.15	
LHS 493	9.36	8.88	8.60	4.33	
LHS 499	8.46	7.91	7.66	3.14	
PJH 4051	10.14	9.60	9.33	4.05	
J2231-7515	14.86	14.82	14.72	1.49	white dwarf
J2231-7514	14.66	14.66	14.44	1.38	white dwarf
LHS 531	6.62	6.08	5.81	3.58	
LHS 532	8.98	8.36	8.11	5.08	

TABLE 3  
DETAILS OF PHOTOMETRIC DISTANCE RELATIONS.

Color	# Stars in Fit	Applicable Range	Coeff #1 $\times (\text{color})^4$	Coeff #2 $\times (\text{color})^3$	Coeff #3 $\times (\text{color})^2$	Coeff #4 $\times (\text{color})$	Coeff #5 (constant)	RMS (mag)
$(B_J - R_2)$	54	not useful	...	...	...	...	...	...
$(B_J - I)$	54	2.48 to 6.95	...	- 0.06597	+ 1.00958	- 3.65843	+ 9.49477	0.74
$(B_J - J)$	54	3.53 to 9.51	+ 0.01720	- 0.44789	+ 4.18392	- 15.61513	+ 25.69047	0.62
$(B_J - H)$	54	4.15 to 10.22	+ 0.01736	- 0.49708	+ 5.13558	- 21.71069	+ 37.74852	0.64
$(B_J - K_s)$	54	4.38 to 10.69	+ 0.01385	- 0.41706	+ 4.52981	- 20.08433	+ 36.70961	0.63
$(R_2 - I)$	54	0.67 to 4.08	...	...	+ 0.07403	+ 1.16691	+ 4.59375	0.76
$(R_2 - J)$	55	1.08 to 6.43	+ 0.03685	- 0.53287	+ 2.68760	- 4.56720	+ 8.21182	0.70
$(R_2 - H)$	55	1.68 to 7.49	+ 0.02066	- 0.37082	+ 2.36926	- 5.37494	+ 9.74196	0.72
$(R_2 - K_s)$	55	1.92 to 8.15	+ 0.01260	- 0.25196	+ 1.78947	- 4.36444	+ 9.10891	0.71
$(I - J)$	55	0.04 to 3.65	...	- 0.19062	+ 1.13456	- 0.07582	+ 6.05024	1.00
$(I - H)$	55	0.61 to 4.71	...	- 0.17978	+ 1.40873	- 1.58307	+ 6.60017	1.03
$(I - K_s)$	55	0.91 to 5.37	...	- 0.16765	+ 1.47110	- 2.23929	+ 7.04432	0.99
$(J - H)$	55	not useful	...	...	...	...	...	...
$(J - K_s)$	55	not useful	...	...	...	...	...	...
$(H - K_s)$	55	not useful	...	...	...	...	...	...



TABLE 4

DISTANCE ESTIMATES AND TRUE DISTANCES FOR OBJECTS WITH  $\mu > 1.0''/\text{YR}$  AND  $R < 16.5$  FOUND BETWEEN  $\delta = -57.5^\circ$  AND  $-90^\circ$ .

Object	# est	dist est	dist YPC	dist HIP	Notes
New discoveries:					
SCR0342-6407	11	$39.3 \pm 11.7$	...	...	CTIOPI
SCR1138-7721	11	$8.8 \pm 1.7$	...	...	CTIOPI
SCR1845-6357	6	$3.5 \pm 0.7$	...	...	CTIOPI, no $B_J$ data, $R_2 - J$ too red
SCR1848-6855	7	$34.8 \pm 9.8$	...	...	CTIOPI
SCR2012-5956	0	...	...	...	CTIOPI, white dwarf, dist 15-25 pc
Previously known objects:					
LHS 124	11	$19.6 \pm 1.2$	...	...	CTIOPI
LHS 128	8	$11.8 \pm 1.1$	$16.9 \pm 2.8$	$19.4 \pm 0.4$	too blue in 3 colors, multiple?
LHS 145	0	...	...	...	CTIOPI, white dwarf
LHS 150	11	$18.3 \pm 1.6$	$15.5 \pm 4.6$	...	CTIOPI
LHS 160	11	$12.2 \pm 0.8$	$12.3 \pm 2.4$	$11.5 \pm 0.3$	
LHS 195	0	...	not useful	$58.8 \pm 3.4$	too blue, too bright
LHS 199	11	$26.9 \pm 3.2$	$22.5 \pm 5.8$	...	CTIOPI
LHS 204	0	...	$35.1 \pm 13.5$	$68.7 \pm 4.8$	too blue, too bright
LHS 205	11	$12.0 \pm 0.8$	$12.9 \pm 1.9$	...	CTIOPI
LHS 34	0	...	$7.1 \pm 0.4$	...	CTIOPI, white dwarf
LHS 263	11	$8.2 \pm 1.2$	...	...	CTIOPI
LHS 268	0	...	$46.3 \pm 21.2$	$60.8 \pm 3.7$	too blue, too bright
LHS 271	11	$8.0 \pm 1.4$	...	...	CTIOPI
LHS 328	11	$25.1 \pm 3.1$	...	...	
LHS 329	11	$27.4 \pm 4.6$	...	...	
LHS 475	11	$11.8 \pm 3.0$	...	...	CTIOPI
LHS 493	11	$16.5 \pm 1.9$	...	...	CTIOPI
LHS 499	11	$16.7 \pm 1.3$	$15.9 \pm 3.1$	...	
PJH 4051	11	$26.1 \pm 3.5$	...	...	
J2231-7515	0	...	...	...	CTIOPI, white dwarf
J2231-7514	0	...	...	...	CTIOPI, white dwarf
LHS 531	11	$6.2 \pm 0.5$	$8.3 \pm 0.7$	$8.6 \pm 0.1$	multiple?
LHS 532	11	$9.1 \pm 1.2$	...	...	CTIOPI